# LABORATORY EVALUATION OF EPDM ROOF MEMBRANES: A 17-YEAR HISTORY OF PERFORMANCE

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Single-ply rubber sheets, based upon ethylene propylene diene terpolymers (EPDM), have steadily increased in usage for roof membranes over the past 20 years. The use of EPDM has significantly advanced the technology of roofing, particularly for large, low-slope, commercial buildings. This paper summarizes the physical properties of membrane samples obtained from 45 EPDM roofs that range from three to 17 years of age, and compares the data to laboratory heat aging and xenon-arc accelerated weather testing. Basic physical properties such as tensile strength and elongation are reported for all samples. More sophisticated, time consuming tests, such as brittleness temperature, were performed on some of the samples. The roof aged sheet properties are evaluated against established standards for elastomeric sheets.

**KEYWORDS**

Appearance, brittleness temperature, differential scanning calorimetry (DSC), elongation, ethylene propylene diene terpolymers (EPDM) roof membranes, glass transition temperature, hardness, tear resistance, tensile strength.

## INTRODUCTION

EPDM polymer became commercially available in 1963, and by 1965 sheets were manufactured from formulations consisting of EPDM polymer, carbon black, process oil, zinc oxide and curing agents. Sheets made from early formulations (mid-1960) had excessive shrinkage due to the use of process oil that was too volatile. When the sheet was heated by the sun, some of the oil left the rubber and shrinkage occurred. The pioneers of EPDM formulations for roofing and waterproofing quickly learned to use very low volatility oil that would remain in the sheet and not cause long-term oil loss which induced shrinkage.

By 1970, the formulation chemistry and manufacturing technology was established to produce EPDM sheets that had the proper balance of physical and chemical characteristics suitable for roof membranes. Not only was it necessary to have desirable properties initially engineered into the membrane, but the properties had to be maintained above minimum levels for satisfactory long-term performance.

All roofing materials are affected by the combined influence of water, solar ultraviolet radiation, heat, ozone and thermal cycling. Biological attack, atmospheric pollution and physical damage are additional factors that can diminish the performance of the roofing membrane. Roof system design can magnify or minimize the exposure of the roof membrane to environmental stresses that cause deterioration and eventual failure of the roof system. The combined affect of all these factors is so complex that even the most rigorous laboratory test program alone cannot completely predict the long-term performance of roofing membranes and system components.

An essential component of membrane performance evaluation for research purposes is the periodic inspection, sampling and laboratory testing of actual field aged roof sheet. Samples must be collected from all system types, in hot and cold climates. Unusual exposure conditions must be examined and taken into consideration to accurately assess the condition of the membrane.

Studies relating actual outdoor, real-time exposure to laboratory accelerated weathering have shown that EPDM rubber sheets have outstanding long-term weather resistance, although certain physical properties do change as the exposure period increases. Even though EPDM has earned a reputation for its weatherability, some questions remain to be answered:

- What important physical properties change upon exposure?
- How do aged properties compare with ASTM D 4637[1] new material standards and the Midwest Roofing Contractors Association (MRCA) ME-20[2] performance criteria for elastomeric membranes?
- Can the age of an EPDM roof be determined by physical property evaluation, surface appearance or thermal analysis?
- How do aged physical properties of EPDM membranes in exposed systems compare to membranes in protected systems?

This paper will provide some insight on the answers to these questions. It must be emphasized that the data presented herein is based upon long-term exposure of Carlisle SynTec Systems formulated sheet.

## THE TEST PROGRAM

Membrane samples were cut from 45 roofs representing 13 states. The samples were obtained from standard roofs (not experimental) at random by persons unaware of the test protocol. The buildings are hospitals, colleges, schools, laboratories, distribution centers, hotels, churches, stores, banks, manufacturing facilities and offices. The roof systems are fully adhered (18), mechanically fastened (4), ballasted (20) and "insulated" membrane assembly (3).

The samples were tested for tensile strength and ultimate elongation in the machine direction using ASTM Test Method D 412.[3] The results are shown in Figures 1 through 4. The tear resistance was determined in the machine direction using ASTM Test Method D 624,[3] and the results are

shown in Figures 5 and 6. Membrane hardness, determined with a Shore A Durometer as specified by ASTM Test Method D 2240,[3] is shown in Figures 7 and 8.

Most of the samples were analyzed using thermogravimetric analysis (TGA), and some of the samples were tested for glass transition temperature using differential scanning calorimetry (DSC). Both techniques are forms of thermal analysis in which a physical property of a substance is measured as a function of temperature. Examples of physical properties include mass, temperature, enthalpy and dimension.

TGA measures the change in mass as a function of temperature. The sample is heated at a fixed rate in a controlled furnace atmosphere. As the sample is heated, components begin to volatilize. The resulting mass change versus temperature curve (also called a thermogram) provides valuable information on the thermal stability and composition of the material. It is important to remember that most of the information obtained from the TGA is empirical in nature—that implies it is dependent on instrument parameters such as heating rate and atmospheric conditions around the sample. A standard thermogram is shown in Figure 10. It can be seen that as the sample is heated in a nitrogen atmosphere, polymer and oil components volatilize simultaneously. After this step is completed, the atmosphere is switched to air and combustion of any other organic material occurs. In the case of black EPDM rubber compounds, this component is usually carbon black. At the end of the test, an ash remains which can be used for elemental analysis to determine if the membrane contained ingredients like zinc oxide, titanium dioxide, talc, clay, mica, etc. Comparison of scans of unaged and aged membrane gives us the ability to monitor how the materials composition is affected by long-term weathering. For instance, oil or plasticizer loss can be monitored and subsequently correlated to changes in physical properties.

Differential scanning calorimetry (DSC) measures the heat energy emitted or absorbed by the sample as the temperature is increased at a controlled rate. For rubber, it is most useful for determining phase changes and the glass transition temperature. The glass transition temperature is the midpoint of the temperature range where the sample changes from a rubbery to a hard and relatively brittle material. Five samples were subjected to DSC analysis and the glass transition temperature was compared to the brittleness temperature as determined by ASTM Test Method D 746.[4] An example of a DSC analysis is shown in Figure 11.

## PHYSICAL PROPERTY TEST RESULTS

The physical property test results were separated into two major groups; values for exposed membranes and "protected" membranes. Exposed membranes were taken from either fully-adhered roof systems or mechanically-fastened systems. The term "exposed" means that the membrane was not protected by design from solar radiation. Exposed membrane properties are shown in Figures 1, 3, 5 and 7. Each bar represents a separate roof and the values for tensile strength, elongation, tear resistance and hardness match position by position through each bar graph. As an example, the three-year old roof had a tensile strength of 10.6 MPa, an elongation of 530 percent, a tear resistance of 42.0 kN/m and a hardness of 60.

For this paper, "protected" membranes are defined as ballasted or insulated (also known as protected membrane roofs). Figures 2, 4, 6 and 8 show protected membrane properties. The ballasted systems have some protection from solar radiation depending upon the ballast coverage density, and the insulated membranes are protected by insulation/ballast.

### Tensile Strength

The tensile strengths ranged from 10.5 to 14.8 MPa for exposed membranes and 11.1 to 13.7 MPa for protected membranes (see Figures 1 and 2). The ASTM minimum requirement for new sheet is 9.0 MPa and the MRCA minimum performance requirement is 6.0 MPa. All aged sheet tensile strengths exceed ASTM and MRCA requirements for new EPDM membrane.

### Elongation

The ultimate elongations ranged from 230 to 530 percent for exposed membranes and 290 to 480 percent for protected membranes (see Figures 3 and 4). The ASTM minimum requirement for new sheet is 300 percent and the MRCA minimum performance requirement is 250 percent. All sheet ultimate elongations, except the 17-year old exposed membrane (230 percent), exceed the MRCA performance requirement for elongation.

### Tear Resistance

Tear resistance ranged from 42.0 to 57.8 kN/m for exposed membranes and 45.5 to 59.5 kN/m for protected membranes (see Figures 5 and 6). The ASTM minimum requirement for new sheet is 26.0 kN/m and the MRCA performance requirement is 21.0 kN/m. All aged sheet tear resistances exceed ASTM and MRCA requirements.

### Hardness

Hardness ranged from 60 to 81 for exposed membranes and 62 to 76 for protected membranes (see Figures 7 and 8). There are no ASTM or MRCA requirements for hardness. Although there are no standard requirements for hardness, it is an important gauge to measure the cure state of rubber articles. As EPDM sheets weather, the hardness generally increases. The aged hardness can be compared to the original unaged hardness.

### Brittleness Temperature

The brittleness temperatures ranged from −62°C for unaged sheet to −70°C for aged membrane (see Figure 9). The ASTM minimum requirement for new sheet is −45°C and the MRCA performance requirement is −40°C. All samples tested passed the low temperature requirements. The lower the brittleness point, the better the membrane is for low temperature flexibility.

### Glass Transition Temperature

The glass transition temperature remained at −49°C for all samples; aged and new. No standard specification exists for glass transition temperature.

### Appearance

Photographs were taken of new and aged membranes and enlarged to 2X. Figure 12 shows the surface appearance of protected EPDM membranes from five, eight and 10-year old roofs compared to new membrane. Figure 13 is a pho-